Radial Line Slot Array (RLSA) Antenna Design at 28 GHz Using Air Gap Cavity Structure

R. A. A. Kamaruddin[1], I. M. Ibrahim[1], M. A. A. Rahim[1], Z Zakaria[1], N. A. Shairi[1], T. A. Rahman[2]
[1]*Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*
[2]*Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia*
rabiatulazian93@gmail.com

Abstract*—A radial line slot array antenna is presented and experimentally discussed for a fifth generation (5G) mobile communication system that resonates at the frequency of 28 GHz. Additionally, it is low profile, simple structure, easy to manufacture with high gain and radiation characteristics. The two models of the antenna were simulated with different cavity thickness, which are 2.5 mm and 3.2 mm. The antenna cavity consists of an FR4 hybrid with an air gap that has produced an equivalent dielectric substrate value of 1.13. The antenna has been fed by a modified dielectric coated of 50 Ω SSMA connector as a coaxial to waveguide transition. Details of the antenna model and simulation result are presented and discussed clearly in this paper. The Computer Simulation Technology Microwave Studio 2015 software has been used as a tool to assist the simulation work. The simulation result gave the return loss of -13.99 dB at 28 GHz for air gap cavity of 2.5 mm. The higher value gain of 21.70 dBi for 3.2 mm and less than -10 dB impedance with the bandwidth from 24.27 – 32 GHz is realized. The beamwidth obtained is below 15° of E and H planes for 2.5 mm.

***Index Terms*—Radial Line Slot Array Antenna; 5G; 28 GHz; Air Gap Cavity Structure.**

I. INTRODUCTION

The Radial Line Slot Array (RLSA) was introduced at Ka-band for space used [1]. It was also designed for Direct Broadcast from Satellite (DBS) reception and satellite on the move (SOTM) [3] which operated at Ku-band. The RLSA antenna mostly used FR4 with the permittivity value of 4.7 [4] and 5.4 as in [5-7]. There are researchers used the brass as a conductor and the air as a cavity in [3]. The relative permittivity produced was 1.06 [8] while (ε_r = 1.07) was reported when they used Rohacell WF51 [9].

The RLSA antenna is known as a good radiator and as well as a good receiver for point to point communication application [4, 5, 8, 10-11]. It can be designed for linear, circular and elliptically polarization [11]. The RLSA antenna has proved good in return loss, efficiency and directivity gain [1, 3, 7-9, 11]. However, Peng has reported the efficiency of High Power Microwave (HPM-RLSA) will drop when the aperture size is reduced due to the rational asymmetry of illumination [12].

In this paper, we proposed the RLSA antenna with a hybrid of two different dielectric substrates as the cavity structure; which are FR4 and Air Gap. The 1.13 equivalent dielectric permittivity was obtained. The antenna has been designed at 28 GHz frequency that suitable for wireless communications.

II. ANTENNA DESIGN

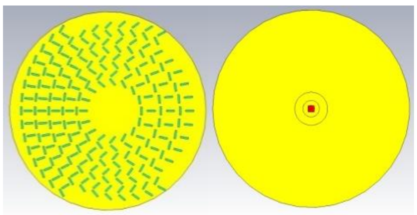
A radial line slot array antenna has been developed; consist of dielectric substrate sandwiched by copper plates as illustrated in Figure 1. It shows the side view of the antenna where ‘a’ is coppers as the radiating surface and the ground plane whiles the ‘b’ is the substrate.

The radius of the radiating surface is 60 mm along the x-axis and the thickness of the cavity or also known as the height of the antenna *h* along the y-axis is allocated on the surface of a grounded dielectric substrate.

The three essential parameters for the design of RLSA antenna are the frequency of operation (f_o), dielectric permittivity of the substrate (ε_r) and the height of the substrate (h). The dielectric substrate material (ε_r) selected for this design is FR4 and Air Gap; which produces a new equivalent dielectric value of 1.13.

Figure 1: The layer of the prototype antenna

Figure 2 illustrates the prototype of the antenna design. On the radiating surface of the antenna were allocated slots which are holes as Figure 2 (a). In order to get the shape of the rectangular slot array, it needs the equation to get the value of the slot length by using λ_g [14] from the equation (1) and (2). While the Figure 2 (b) shows the ground of the RLSA antenna with coaxial waveguide as a feeder.



(a) *(b)*

Figure 2: Antenna structure (a) Front view (b) Back view

Figure 3 shows the proposed antenna structure for the RLSA. The value of *h* is tuned to provide optimum impedance bandwidth [5,7].

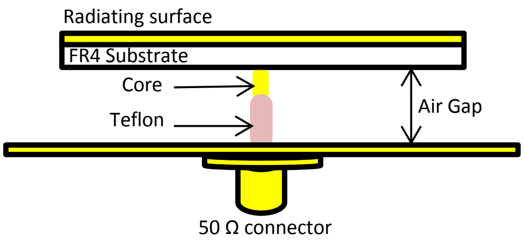


Figure 3: Structure illustrates the feeder inside the cavity [4,10].

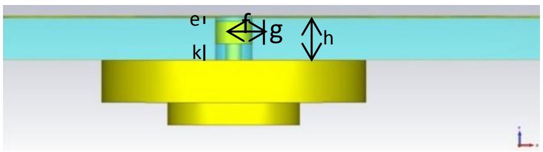


Figure 4: Side view structure of the antenna cavity

The RLSA antenna using RT Duroid 58800 with high frequency laminated with a disk ended of 50 Ω dielectric coated SSMA probe was reported in [11]. In this paper, the idea was extended to include a disk ended of 50 **Ω** dielectric coated SSMA probe with FR4 as the substrate. Technically, the rectangular shape is proposed as the air gap at the top of the radiating surface on the circular shape board. To achieve optimized performance; they tuned the value of e, g and k as shown in Figure 4.

This research proposed a simpler feed probe design as shown in Figure 3. The radial waveguide is fulfilled with a dielectric material of suitable relative permittivity (ε_r), here we have chosen 1.13 in the space of *d* , hence *d* has a relation to the ε_r.

$$d < \frac{\lambda_g}{2} \tag{1}$$

$$\lambda_g = \frac{c}{\sqrt{\mu_r \varepsilon_r}} \tag{2}$$

Where:

$\boldsymbol{\lambda_g}$: wavelength in the guide
c: speed of light
$\boldsymbol{\mu_r}$: relative permeability
d: the h value which is the thickness of the cavity

The value of ε_r must be greater than 1 to prevent the grating lobes from appearing in the radiation pattern. The dielectric material is functioning to create a slow wave in the cavity resulting in **λ**g > **λ**o (free space wavelength).

$$c = \varepsilon \, \frac{A}{d} \tag{3}$$

Where:

c: capacitor
ε: dielectric value
A: the area of slot
d: the slot thickness

The capacitance is influenced by dielectric permittivity, the size and the slot thickness. In this study, the slot length is already fixed to a half wavelength. The dielectric relative permittivity is 1 since it is an air gap. Figure 5 shows the radiating slot shape on the radiating surfaces.

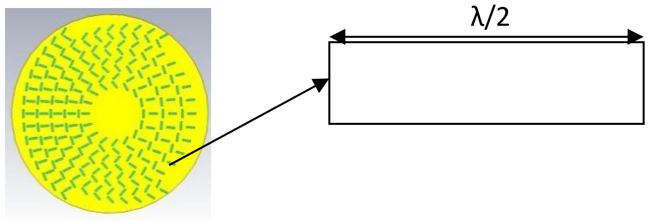


Figure 5: The shape of radiating slot

III. RESULT AND DISCUSSION

The proposed design was simulated by using the CST software. Table 1 shows the specification of the parameter used to design the RLSA antenna.

Table 1
Design Specification

Parameter	Value
Center frequency, f_o	28 GHz
Radius of antenna	60 mm
No. of slots in first ring	16
Cavity of thickness (Maximum)	3.2 mm
Thickness of radiating surface (copper)	0.035 mm
Thickness of ground (copper)	0.035 mm
Relative permittivity of FR4	1.13
Slot width	1.0 mm
Slot length	5.0 mm

Figure 6 shows the return loss result for the optimization of the proposed design. The air gap cavity is λ/4.

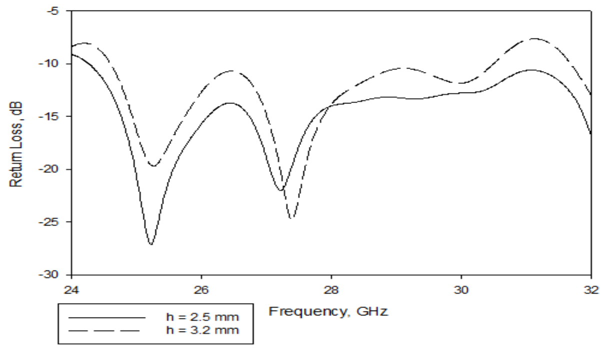


Figure 6: Return loss of the proposed air gap cavity substrate design with variable h.

Table 2 shows the best performance obtained when h = 2.5 mm. The |S11| value recorded -13.99 dB at 28 GHz and wide impedance bandwidth was obtained from 24.62 – 30.49 GHz with the gain 21.64 dBi. The air gap cavity of 3.2 mm has shown the return loss obtained -13.84 dB at 28 GHz with the gain 21.70 dBi.

Table 2
Comparison Parameters of Simulation Results

	Simulation	
Height of Cavity (mm)	h=λ/4	h=λ/3
Operating Frequency (GHz)	28	28
Bandwidth (GHz)	24.62-30.49	24.27-32.00
Gain (dBi)	21.64	21.70
Return Loss (dB)	-13.99	-13.84

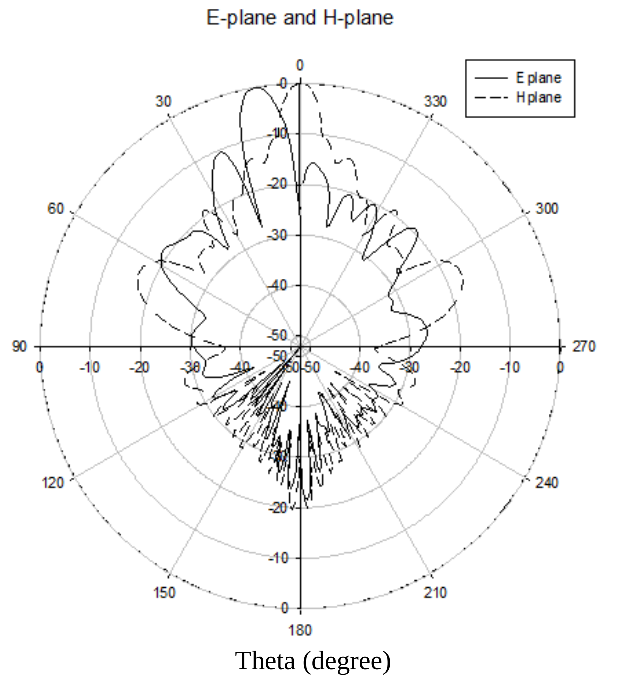


Figure 7: Radiation pattern at frequency 28 GHz for λ/4 cavity thickness

Figure 7 showed the comparison of E-plane and H-plane for λ/4 cavity thickness at a frequency 28 GHz. The directional directivity of the radiation pattern was obtained.

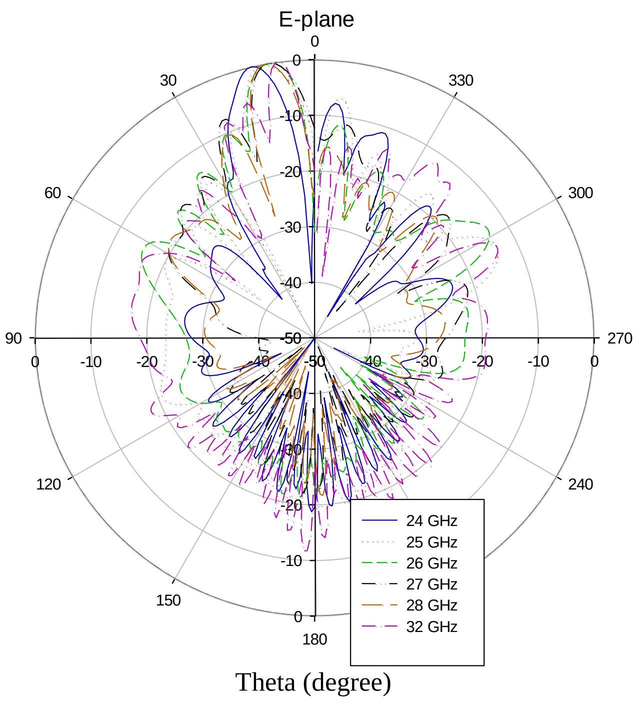


Figure 8: The comparison radiation pattern at E-plane for λ/4 cavity thickness

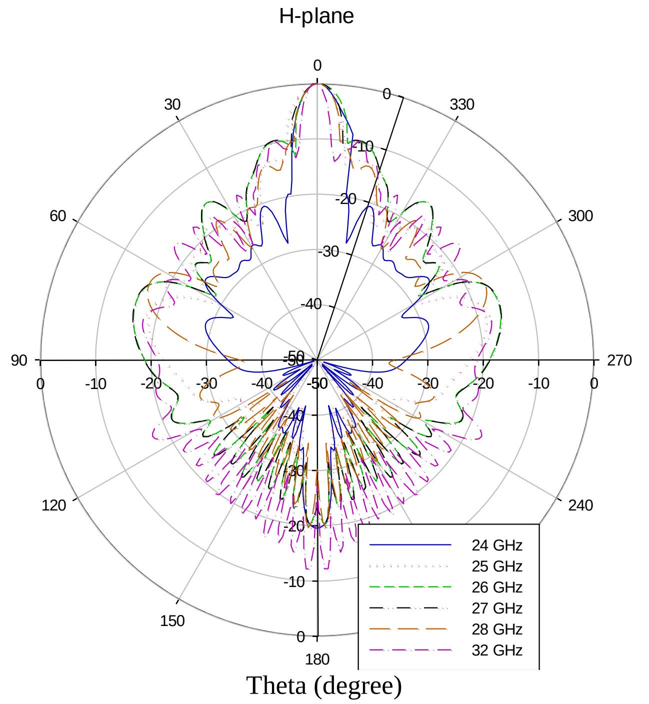


Figure 9: The comparison radiation pattern at H-plane for λ/4 cavity thickness

Figure 8 and Figure 9 are comparing the simulated radiation pattern at different frequencies such 24 GHz, 25 GHz, 26 GHz, 27 GHz, 28 GHz and 32 GHz for air gap cavity of 2.5 mm at the E - plane and H-plane. The simulated result directivity has shown that air gap cavity of 2.5 mm is 21.64 dBi while 3.2 mm is 21.70 dBi at 28 GHz.

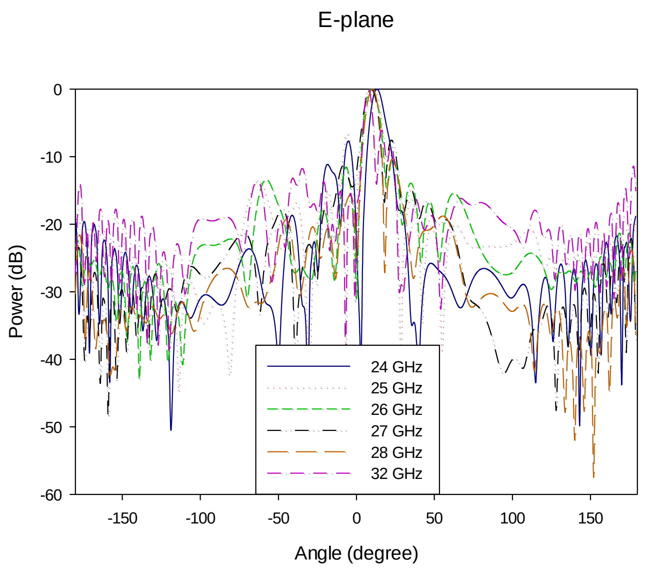


Figure 10: Cartesian plot of E-plane for λ/4 cavity thickness

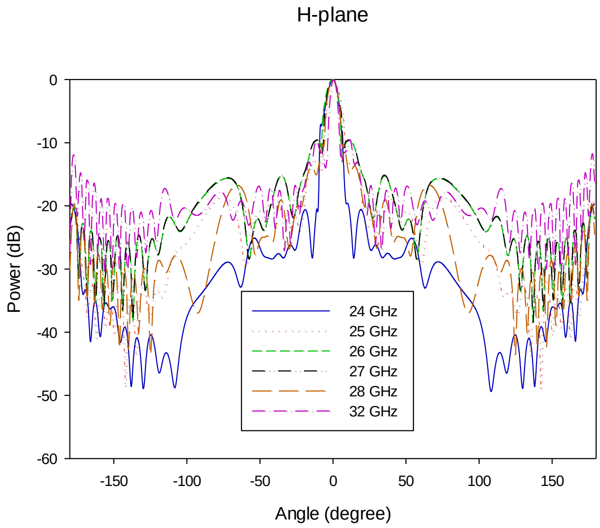


Figure 11: Cartesian plot of H-plane for λ/4 cavity thickness

Figure 10 and 11 shows the Cartesian plot of the radiation pattern. Table 3 shows the comparison of the different frequencies at λ/4 cavity thickness. The squinted value of the frequency of 28 GHz is 10° at the E - plane. All frequencies had shown the best results for point to point communication because they achieved the squinted value of less than 15° and 17 dB for side lobe ratio by referring the ETSI (European Telecommunication Standard Institute).

Table 3
Comparison of Antenna Parameter with Different Frequencies with Air Gap Cavity of 2.5 Mm

Frequency of RLSA Antenna for h = 2.5 mm	24.00 GHz	25.00 GHz	26.00 GHz	27.00 GHz	28.00 GHz	32.00 GHz
S_{11} (dB)	-9.11	-20.67	-15.69	-18.88	-13.99	-16.87
Simulated Gain (dBi)	22.54	21.01	20.89	20.80	21.64	16.30
Squinted degree (°)	13	11	9	9	10	8
Beamwidth at -3 dB (°) E-plane	7.77	8.55	8.75	8.42	7.44	4.80
H-plane	6.52	8.57	8.83	8.40	7.48	5.00
Main to Side Lobe Ratio (-dB) E-plane	8.00	6.50	10.00	22.53	10.64	16.00
H-plane	20.67	18.85	9.70	10.65	15.00	9.50
Front to Back Lobe Ratio (-dB) E-plane	19.00	19.00	21.50	22.00	21.60	12.00
H-plane	19.50	19.00	20.50	20.00	19.60	12.00

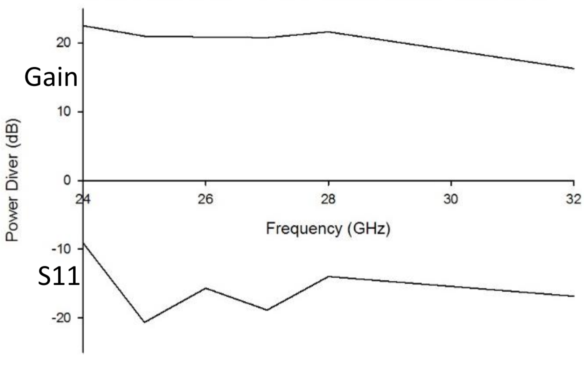


Figure 12: Graph gain and return loss response over frequency

IV. Conclusion

This paper presents the design of a Radial Line Slot Array Antenna with a hybrid of FR4 and Air Gap cavity for use in a 5G communication application. The equivalent air gap substrate with dielectric constant of 1.13 is chosen which gives a percentage of 21.3% bandwidth for λ/4 cavity thickness and 27.47 % for λ/3 cavity thickness. The cavity thicknesses of RLSA antenna for 2.5 mm have a better linear polarized radiation pattern as the RLSA specification for point to point communication system. The proposed antenna thickness was varied in order to observe the desired value of operating frequency with a wide bandwidth of more than 1 GHz.

Acknowledgment

I am thankful to the Universiti Teknikal Malaysia Melaka (UTeM) and Centre for Research and Innovation Management (CRIM) UTeM for sponsored and facilitate our research publication.

References

[1] T. X. Nguyen, R. S. Jayawardene, Y. Takano, K. Sakurai, T. Hirano, J. Hirokawa, M. Ando, O. Amano, S. Koreeda and T. Matsuzaki. "Study of a high gain RLSA Antenna in Ka-band for space uses," *In Proceedings of the 2013 International Symposium on Electromagnetic Theory*, pp 611-613, 2013.

[2] J. Suryana and D. B. Kusuma, "Design and implementation of RLSA antenna for mobile DBS application in Ku-band downlink direction," *IEEE* [The 5TH International Conference on Electrical Engineering and Informatics, Bali, Indonesia, 2015], pp 341-345, Aug. 2015.

[3] W. A. W. Muhamad, T. A. Rahman and M. F. Jamlos. "The effects of air gap on spider radial line slot array (SRLSA) antenna for point to point application," *IEEE Symposium on Wireless Technology and Applications (ISWTA), Kuching, Malaysia*, pp 388-390, Sep. 2013.

[4] I. M. Ibrahim, T. A. Rahman, S. Z. Illiya and M. I. Sabran, "Aperture slot size effect to wide band open air gap radial line slot array performance," *IEEE Microwave and Optical Technology Letters*, vol. 56, pp. 2974-2978, Dec. 2014.

[5] I. M. Ibrahim,T.A. Rahman, M.I. Sabran and M. F. Jamlos. "Bandwidth enhancement through slot design on RLSA performance," *IEEE*, pp 228-231, 2014.

[6] I. M. Ibrahim, T. A. Rahman, M. I. Sabran, U. Kesavan and T. Purnamirza. " Wide band open ended air gap RLSA antenna at 26 GHz frequency band," PIERS Proceeding, Taipei, Mar. 2013, pp 470-474.

[7] J. Bai, J. Lin and J. Hu. "The optimization of Radial Line Slot Antenna," *IEEE Transactions on Antennas and Propagation*, pp 714-717, 2013.

[8] A. Mozzinghi, M. Albani and A. Freni, " Near field focusing for security applications design and optimization of RLSA antennas," *IEEE*, pp 742-745, 2014.

[9] I. M. Ibrahim, T. A. Rahman, T. Purnamirza and M. I. Sabran, "A novel wide band open ended air gap radial line slot array antenna at 5.8 GHz frequency band," *IEEE Microwave and Optical Technology Letters*, vol. 56, pp. 938-944, April. 2014.

[10] I. Maina, T. A. Rahman and M. Khalily, " Bandwidth enhanced and sidelobes level reduced radial line slot array antenna at 28 GHz for 5G next generation mobile communication," ARPN journal of engineering and applied sciences, vol. 10, no. 10, pp 5752-5757, Aug. 2015.

[11] S. Peng, C. W. Yuan, T. Shu, J. Ju and Q. Zhang, "Design of a concentric array radial line slot antenna for high power microwave application," *IEEE Transactions on plasma science*, vol. 43, no. 10, pp 3527-3529, Oct. 2015.

[12] I. Iliopoulos, M. Ettorrer, M. Casaletti, R. Sauleau, P. Pouliguen and P.Potier, "3D near field shaping of a focused aperture," *IEEE* [The 10th European Conference on Antennas and Propagation (EuCAP) Davos, 2016, pp 1-4].

[13] M. Ettorre, M. Casallettti, G. Valerio, R. Sauleau, L. L. Coq, S. C. Pavone and M. Albani, "On the near field shaping and focusing capability of a Radial Line Slot Array," *IEEE Transaction on Antennas and Propagation*, vol. 62, no. 4, pp 1991-1999, Apr. 2014.